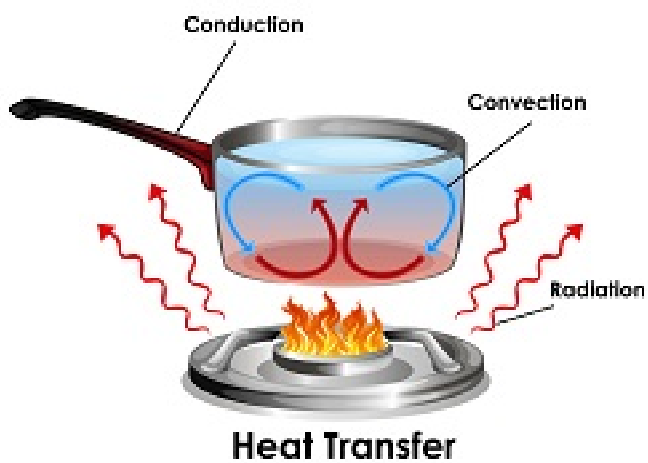
DEPARTMENT OF MECHANICAL ENGINEERING

ABIT

HEAT TRANSFER



MODULE-IV

BOILING AND CONDENSATION

INTRODUCTION:

- Boiling and condensation are the processes , those deal with phase change.
- During boiling there is phase change from liquid to vapour and during condensation there is phase change from vapour to lquid.

Applications

i. Boilers and condensers used in steam power plant,
ii. Nuclear reactors
iii. Evaporator and condenser in air conditioner and refrigerator.

In Boiling and condensation processes

i. Because of phase change the temperature of the fluid remains constant.
ii. The heat transfer coefficient and latent heat related to phase change is higher.
iii. High rate of heat transfer can be obtained.

Boiling

- Boiling is the evaporation which occurs when surface temperature (t_s) is more than saturation temperature of the liquid at the given pressure(t_{sat}).
- Heat is flow occurs from the solid surface to the liquid according to the law

$$Q= h A_s (t_s - t_{sat}) =h A_s \Delta t_e$$

Where, $\Delta T_e = (t_s - t_{sat})$ is known as excess temperature.

Applications:

i. Boilers in Steam power plant
ii. Evaporators in refrigeration and air conditioning systems
iii. Cooing of nuclear reactors and rocket motors.

There are four forms in which the boiling process occur.

1. **Pooling boiling:**

   In pool boiling the liquid neat the heated surface remains stagnant. The movement is because of free convection and there is mixing because of bubble formation. It is seen in steam boilers involving natural convection.

2. **Forced convection boiling:**
   It occurs when the liquid is forced to flow by external means and also through free convection.It is seen in water tube

3. **Sub-cooled or local boiling**

If the temperature of liquid is under saturation temperature and bubbles are induced near the heated surface, then this process occurs.

4 Saturated boiling

If the temperature of the liquid is above saturation temperature and bubbles are formed and driven by buoyancy effects .Such process is known as saturated boiling. Here the vapour bubbles escape from the free surface

Boiling regimes

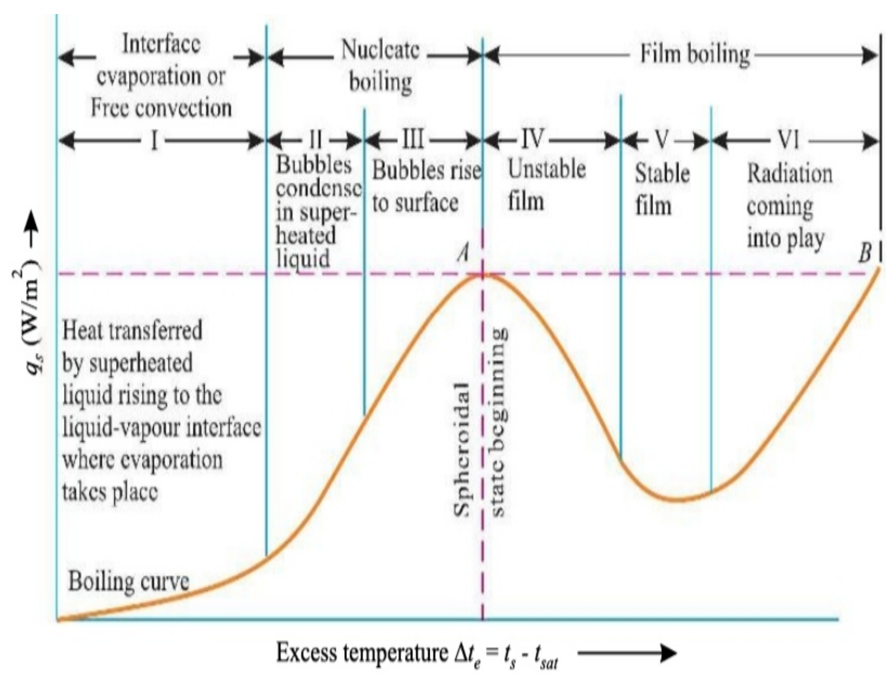
- Since boiling process involves a large number of variables like nature of surface, properties of fluid, vapour bubbles general equation representing the boiling process is not available.
- There are three different regimes of boiling.

1. **Interface evaporation**

   This is the region I which is the free convection zone with no bubble formation. Here the excess temperature Δt_e is very small and nearly $=5^0$C.

2. **Nucleate boiling**

   This includes region II and III. Here there is formation of bubbles which are get condensed without reaching the liquid surface. Region II , where nucleate boiling begins where bubbles are formed and in region III , the bubbles are formed more rapidly and move to the liquid surface and evaporates.



3. **Film boiling**

- This includes region IV, V and VI. The heat flux which increases up to region III decreases in region IV.
- Because the bubbles which are formed rapidly forms a blanket and do not allow the fresh liquid from taking their place. Since the thermal resistance of vapour film is more than the liquid the heat flux drops with increase in temperature .
- With further increase in temperature the vapour film becomes stable and heat flux becomes minimum.
- The temperature is very high and a considerable amount of heat is lost by radiation, which is shown by region VI.

Critical heat flux or burn out point

- It is the point where heat flux is maximum during transition from nucleate boiling to film boiling.
- If the heat flux is not maintained below it the metallic surface may melt or get damaged.
- Hence it is known as burnout point.

CRITICAL HEAT FLUX APPARATUS

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FACTORS AFFECTING NUCLEATE BOILING

i. **Material ,shape and condition of the heating surface:**

- The heat transfer coefficient in boiling is largely affected by the material of the heating surface under ideal condition of pressure and temperature difference.
- Condition of heating surface like roughness also affects the heat transfer rates . More roughness gives better heat transfer.

ii. **Liquid properties**

- If viscosity is more then large size bubbles are formed which results in decrease in frequency of bubble formation leading to reduced heat transfer.
- Similarly , if thermal conductivity of liquid is high it results in increased heat transfer.

iii. **Pressure**

- Initially with increase in pressure maximum allowable heat flux increases and with further increase heat flux decreases.

iv. **Mechanical agitation**

- If agitation is more heat transfer rate is also more.

BOILING CORRELATIONS

- In boiling heat transfer is caused by excess temperature, written as

$$\Delta t_e = t_s - t_{sat}$$

- The governing equation is

$$Q = hA\Delta t_e$$

Where h is the boiling film coefficient.

NUCLEATE POOL BOILING

- According to Rosenhow , for nucleate pool boiling following correlation exists:

$$q_s = \mu_l . h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma} \right]^{0.5} \left[\frac{c_{pl} . \Delta t_e}{C_{sl} . h_{fg} . \Pr_l^n} \right]^3$$

Where, q_s =surface heat flux. W/m^2,

μ_l =liquid viscosity, kg/ms,

h_{fg} =enthalpy of vaporization,J/kg

ρ_l =density of saturated liquid, kg/m^3,

ρ_v =density of saturated vapour,kg/m^3,

σ =surface tension of theliquid-vapour interface, N/m,

c_{pl} =specific heat of saturated liquid,J/kgK,

Δt_e= (t_s-t_{sat})=excess temperature,

C_{sl} = surface fluid constant (determined from experimental data),

n= another constant which depends upon the liquid and the surface, for water n=1, while for other liquids n=1.7.

The value of C_{sl}=are given in the table below,

Values of C_{sl} for pool boiling		
SL.NO.	**Liquid-surface**	**C_{sl}**
1	Water-copper	0.013
2	Water-brass	0.060
3	Water-platinum	0.013
4	Water-ground and polished stainless steel	0.008
5	Water-mechanically polished stainless steel	0.013
6	Benzene-chromium	0.010
7	Ethanol-chromium	0.0027
8	n-pentane-chromium	0.0150
9	n-butanol-copper	0.003
10	Isopropyl alcohol-copper	0.00225

CRITICAL HEAT FLUX FOR NUCLEATE POOL BOILING

- According to Zuber critical heat flux is given by correlation

$$q_{sc} = 0.18(\rho_v)^{1/2} h_{fg} [g\sigma(\rho_l - \rho_v)]^{1/4}$$

FILM POOL BOILING

- According to Bromley the correlation for film boiling from the outer surface of horizontal tubes

$$(h)^{4/3} = (h_{conv.})^{4/3} + h_{rad.}(h)^{1/3} \text{..............(1)}$$

- The above equation is difficult to solve, can be rewritten as,

$$h = h_{conv.} + \frac{3}{4} h_{rad.} \text{..............(2)}$$

- If radiation is neglected, then

$$h_{conv.} = 0.62\left[\frac{k_v^3 \rho_v (\rho_l - \rho_v) g (h_{fg} + 0.4 c_{pv} \Delta t_e}{\mu_v D \Delta t_e}\right]^{1/4} \text{..............(3)}$$

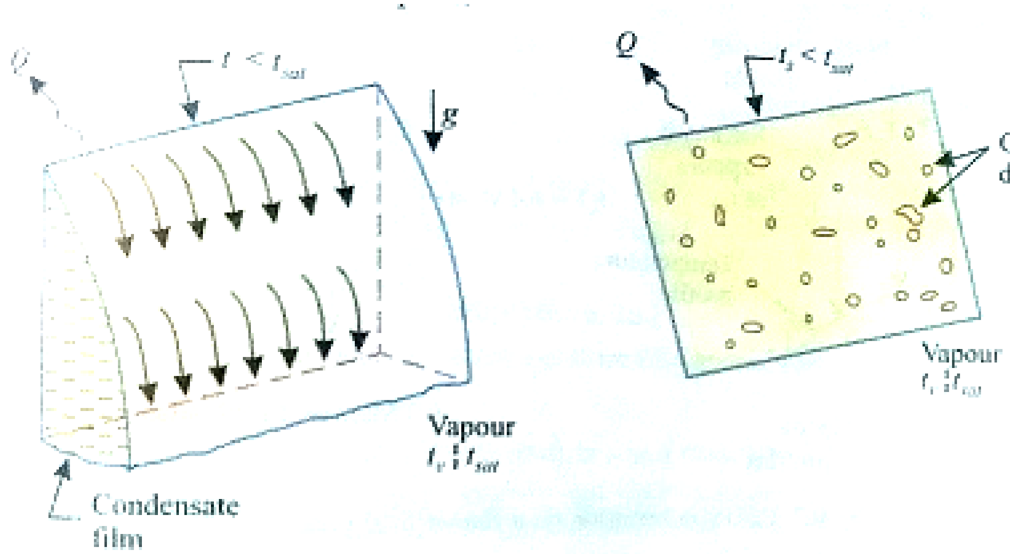
Where , D is the outer diameter of the tube.

CONDENSATION HEAT TRANSFER

- Condensation is the process which occurs when a saturated vapour comes in contact with a surface having a temperature less than the saturation temperature at that given pressure.
- There are two different processes of condensation

(i) Film condensation

(ii) Drop wise condensation



(i) Film condensation (ii) Dropwise condensation

Fig. Film and dropwise condensations on a vertical surface.

(i) Film condensation

- When condensation occurs by wetting the surface and forming a liquid film, then it is called film condensation.
- As the liquid moves down by gravity its thickness increases and the thermal resistance also increases, which reduces the heat transfer.
- This is the case of combined mode of heat transfer, first within the film by convection and then to the solid surface by conduction.
- Due to this heat transfer rate in film condensation is lower compared to drop wise condensation.

(ii) Drop wise condensation

- In this type vapour is converted in to small liquid droplets which grow in size and fall down the surface in a random manner.
- Heat transfer in this type of condensation is more because a large surface is directly exposed to heat transfer.
- The heat transfer coefficient is 5 to 10 times larger compared to film condensation.
- Drop wise condensation is preferred to film condensation, but it is difficult to achieve in practice.